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**SUBJECT:** Landing on Slippery Runways

**ATA NO:**

**APPLIES TO:** All 707, 727, 737, 747, 757, 767, and 777

**Background Information**

The FAA is recommending operators of turbojet airplanes further develop procedures for flight crews to assess landing performance based on actual weather and runway conditions existing at time of arrival rather than based on conditions presumed at time of dispatch.

The words “contaminated” and “slippery” are commonly used in the aviation industry to describe the precipitation on a runway. Although there are specific differences between a contaminated and a slippery runway (as described later), for the purposes of this bulletin, the word “slippery” will be used to mean either “slippery” or “contaminated.”

Each year there are a number of landing overruns where slippery runways or crew procedural deviations are contributing factors. Often, these occurrences are due to a combination of issues such as weather, runway conditions, the airplane’s weight, braking systems to be used, improper flight crew technique, or lower than expected runway friction.
Flight crew and airline operational personnel should ensure they are familiar with factors that may affect an aircraft’s stopping distance so they may make appropriate allowances in calculating the distance required to stop when landing on a slippery runway.

This bulletin is intended to remind flight crews and operators of the factors that affect an airplane’s ability to stop on a slippery runway, the runway condition information that is available to flight crews, and the Boeing *Flight Crew Training Manual* (FCTM) recommended landing procedures and techniques.

Note: The specific information in this bulletin covers the FCTM and/or the Boeing *Flight Crew Operations Manual* (FCOM) information for the 737, 747-400, 757, 767, and 777 model airplanes. In general, the information in this bulletin is also applicable for the 707, 727, and 747 models. Operators should review their operating material (and applicable Boeing documents) used for these models. Boeing Flight Operations Engineering can be contacted with questions on the specifics for these airplanes. The 787 performance information is also expected to be consistent with this bulletin.

Note: A corresponding Flight Operations Bulletin (FOB) addresses the 717, DC-8, DC-9, DC-10, MD-80, MD-90, MD-10 and MD-11 models and will be released in October 2007.

**Introduction**

Boeing provides two different landing distance data sets to operators - Dispatch data and Operational data.

- Dispatch landing data is used during flight planning to determine the maximum takeoff weight at which the airplane can land within the available landing distance at the destination/alternate airport. The data is based on specific regulatory requirements that address dry, wet and slippery runway conditions. This data is also referred to as “certified data.” The data does not provide distance requirements to cover all operational landing situations. The effect of thrust reversers is not included in the dispatch landing data. Wet/slippery conditions are accounted for by factoring the dry runway dispatch landing data (see FAA Code of Federal Regulations, CFR 121.195 (d)).

- Operational data is provided by Boeing as Advisory-Normal Configuration Landing Distance data in the Performance Inflight (PI) section of the Quick Reference Handbook (QRH). This data is also referred to as “operational data,” “enroute data,” or “advisory data.” The data provided by Boeing as advisory landing distance data has always been based on the use of reverse thrust.

Boeing QRH advisory landing distance data is provided as unfactored data, i.e., there is no margin applied to the landing distance, for operators who use FAA
requirements. This may change in the future to include a 1.15 factor as a result of FAA and industry activity.

The advisory data provided in the QRH for operators who use JAA requirements includes a 1.15 factor as required by JAR Ops rules.

To accurately determine the operational landing distance required, it is important that flight crews review the information available regarding weather and runway conditions, and make appropriate allowances to their calculations for any conditions or landing techniques that are different from those used to calculate the advisory data.

An important consideration in the determination of landing distance is the condition of the runway. Information about runway condition is often available through three main sources:

- Pilot reports (PIREPS)
  - Qualitative terms of braking action such as “good, medium, poor” or “good, fair, poor, nil”
- Runway surface description
  - Physical description of runway surface and contaminant, e.g., 6 mm of wet snow, patches of ice, compact snow
- Runway friction reports
  - Measured by friction reporting vehicles designed for this purpose, using the Greek letter, μ, (μ) and can be reported as either a whole number or a decimal (e.g., 40, 0.40)

In August, 2006 the FAA hosted a workshop to address braking action terms and their correlation with varied runway surface conditions. The workshop included U.S. airline technical pilots and other interested parties. The results of the FAA workshop are presented on pages 4 and 5 of this paper. The content is reproduced here without modification although the format has been revised to present the information on two pages. Table 1 (page 5) is a voluntary operational guide for flight crews and is expected to be the starting point for future FAA guidance to be developed for winter operations.
Braking Action Terms & Correlation with Runway Surface Conditions (Part 1 of 2)

Boeing Note: This page is advisory information as developed by a team of US airline technical pilots and other interested parties. The creation of the table was initiated by a FAA workshop on runway condition reporting held in August of 2006.

BRAKING ACTION

PIREPS
When braking action conditions less than “good” are encountered, pilots are expected to provide a PIREP based on the definitions provided in the table below. Until FAA guidance materials are revised to replace the term “fair” with “medium,” these two terms may be used interchangeably. The terms “good to medium” and “medium to poor” represent an intermediate level of braking action, not a braking action that varies along the runway length. If braking action varies along the runway length, such as the first half of the runway is “medium” and the second half is “poor,” clearly report that in the PIREP (e.g., “first half medium, last half poor”).

Correlating Expected Runway Conditions
The correlation between different sources of runway conditions (e.g., PIREPs, runway surface conditions and mu values) are estimates. Under extremely cold temperatures or for runways that have been chemically treated, the braking capabilities may be better than the runway surface conditions estimated below. When multiple sources are provided (e.g., braking action “medium,” runway covered with ice and runway mu is 27/30/28) conflicts are possible. If such conflicts occur, consider all factors including data currency and the type of airplane from which a PIREP was given. A valid PIREP or runway surface condition report is a more reliable indicator of what to expect than reported runway mu values.

Runway Friction Mu Reports
Mu values in the U.S. are typically shown as whole numbers (40) and are equivalent to the ICAO standard decimal values (.40). Zero is the lowest friction and 100 is the highest friction. When the mu value for any one-third zone of an active runway is 40 or less, a report should be given to ATC by airport management for dissemination to pilots. The report will identify the runway, the time of measurement, the type of friction measuring device used, mu values for each zone and the contaminant conditions (e.g., wet snow, dry snow, slush, deicing chemicals). While the table below includes information published by ICAO correlating runway friction measurements to estimated braking actions, the FAA cautions that no reliable correlation exists. Runway mu values can vary significantly for the same contaminant condition due to measuring techniques, equipment calibration, the effects of contamination on the friction measuring device and the time passage since the measurement. Do not base landing distance assessments solely on runway mu friction reports. If mu is the only information provided, attempt to ascertain the depth and type of runway contaminants to make a better assessment of actual conditions.
Table 1

**BRAKING ACTION**

<table>
<thead>
<tr>
<th>Braking Action</th>
<th>Estimated Correlations</th>
<th>ICAO Code</th>
<th>Mu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Good</strong></td>
<td>Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water depth of 1/8” or less</td>
<td>5</td>
<td>40 &amp; above</td>
</tr>
<tr>
<td></td>
<td>• Dry snow less than 3/4” in depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Compacted snow with OAT at or below -15ºC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good to Medium</td>
<td>-</td>
<td>4</td>
<td>39 - 36</td>
</tr>
<tr>
<td><strong>Medium (Fair)</strong></td>
<td>Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dry snow 3/4” or greater in depth</td>
<td>3</td>
<td>35 –30</td>
</tr>
<tr>
<td></td>
<td>• Sanded snow</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sanded ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Compacted snow with OAT above -15ºC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium to Poor</strong></td>
<td>-</td>
<td>2</td>
<td>29 - 26</td>
</tr>
<tr>
<td><strong>Poor</strong></td>
<td>Braking deceleration is significantly reduced for the wheel braking effort applied. Potential for hydroplaning exists. Directional control may be significantly reduced.</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>• Wet snow</td>
<td></td>
<td>25 - 21</td>
</tr>
<tr>
<td></td>
<td>• Slush</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Water depth more than 1/8”</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Ice (not melting)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nil</strong></td>
<td>Braking deceleration is minimal to non-existent for the wheel braking effort applied. Directional control may be uncertain.</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>• Ice (melting)</td>
<td></td>
<td>20 &amp; below</td>
</tr>
<tr>
<td></td>
<td>• Wet Ice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The ICAO term **Unreliable** and SNOTAM code of “9” indicates contamination is outside the approved operational range for the friction measuring equipment in use and therefore mu values are not provided. This typically occurs in poor or worse conditions (greater than 1/8” of wet snow, slush or standing water) whereby a potential for hydroplaning should be expected. **Use PIREPs and the depth and type of runway contaminants to assess actual braking conditions.**

**Boeing Note:** This page is advisory information as developed by a team of US airline technical pilots and other interested parties. The creation of the table was initiated by a FAA workshop on runway condition reporting held in August of 2006.
Definitions:

Slippery Runway — A runway that does not provide the equivalent braking performance of a dry runway.

Contaminated Runway — A runway that is not dry or wet but with contaminants that have a measurable depth; examples include ice, loose snow, compact snow, slush, or standing water. Boeing advisory landing distance data is conservative and does not take credit for the deceleration effects of a contaminant with a measurable depth. Therefore, the term “Contaminated Runway” can be used interchangeably with “Slippery Runway” for the purposes of this bulletin.

Dispatch — Requirements that must be met before takeoff.

Enroute — Any phase of flight after takeoff but before landing. For the purposes of this bulletin, enroute refers to the period of time during which the pilot is evaluating the upcoming landing operation.

Pilot Information Report (PIREP) — Report by flight crews from previous operations. For the purposes of this bulletin, PIREPs are limited to descriptions of the runway surface condition or braking action.

Braking Action — A subjective description of airplane stopping capability on a slippery runway. The terminology in ICAO Annex 14 is “good,” “good to medium,” “medium,” “medium to poor,” and “poor.” The terminology in the FAA Airman’s Information Manual (AIM) and AC 150/5200-30A is “good,” “fair,” “poor,” and “nil.” Please see the Table 1 for further explanation.

Runway Friction — Runway friction is the capability of the runway surface to convert the vertical load on the braked wheels into a horizontal force to stop the airplane. The Greek letter μ (mu) is typically the symbol for friction and represents the percentage of the vertical load converted into a horizontal force.

QRH Advisory — Normal Configuration Landing Distance — Advisory data contained in the “Performance Inflight” section of the QRH. The data is provided as a function of braking action and is referred to as “QRH landing advisory data” in this bulletin.

Dispatch Landing Data

CFR Part 121.195(b) sets the dispatch requirement for dry runway landing distance (Figure 1). This landing distance is based on certification flight testing which includes an air distance from a 50 foot threshold crossing altitude to touchdown of 800 to 1100 feet.

Following touchdown, maximum manual braking and speed brake deployment is initiated as soon as possible in order to minimize the landing distance. However, reverse thrust is not used; therefore, no credit is taken for reverse thrust in the dispatch landing data.
The flight test demonstrated landing distances represent the shortest landing distances for a given airplane weight and represents the best performance the airplane is capable of (without reversers) for the conditions. In order to account for operational variances from the flight test demonstrations, the minimum legal dry runway landing field length is increased by a factor of 1.67.

The dispatch requirement for a wet or slippery runway, CFR 121.195 (d), is based on the distance computed to meet the dry requirement and then increased by a factor of 1.15.

Operational (or Enroute) Landing Data

Boeing includes slippery runway landing distance advisory information in the PI section of the QRH (Figure 2). Specifically, this data is labeled Normal Configuration Landing Distance and is advisory information only.

Boeing supplies the slippery runway data in the QRH as a function of reported braking action. The braking deceleration used to calculate the “good” braking action data in the QRH is consistent with wet runway testing done on early Boeing airplane models. The lowest performance level calculated is consistent with braking on wet ice (defined as “nil” in Table 1 on page 5). This is conservatively used by Boeing to define the “poor” braking action data in the QRH.

The most adverse braking condition, based on reliable expected or actual braking reports, or runway contaminant reports for the portion of the runway that will be used for the landing, should be used in the actual landing performance assessment. For example, if the runway surface condition is reported as “fair to poor,” or “fair in the middle, but poor at the ends,” the runway surface condition should be assumed to be “poor” for the assessment of the actual landing distance. Pilot braking action reports are subjective; therefore flight crews must use sound judgment in using them to predict the stopping capability of their airplanes.

The Boeing supplied operational slippery runway landing data is based on flight test parameters for the specific airplane (lift, drag, reverse thrust effect, etc.) and an engineering analysis of the effect of a slippery runway on the ability of the wheel brakes to stop the airplane.
This operational slippery runway landing data is based on prompt application of all stopping devices (speed brakes, wheel brakes, thrust reversers) and takes into account maximum manual braking or use of the autobrake system.

The advisory data provided in the QRH for operators who use FAA requirements is unfactored, meaning no additional distance margin is added. The advisory data provided in the QRH for operators who use JAA requirements includes an additional 15% distance margin as required by JAR Ops 1.520(b). Operators are encouraged to add additional margins appropriate to their operations. Note that the FAA has released Safety Alert for Operators (SAFO) 06012 which requests US operators to voluntarily add at least 15% margin to their operational landing distance calculations. The FAA is currently considering rulemaking on this subject.
Figure 2 - Operational (or Enroute) Landing Data (777 data used as an example)

Figure 2 presents a 777 QRH chart as an example of advisory data provided by Boeing. Advisory data for other models is presented in a similar format. Data is presented at reference conditions (REF DIST) with adjustments supplied for the operator and/or flight crew to account for the effects of variables such as weight, altitude, wind, slope, temperature, approach speed and the usage of reverse thrust and/or manual speed brakes.

The reference distance is calculated under the following conditions:
- Threshold crossing speed of $V_{REF}$
• Includes distance from 50 foot above threshold to a 1000 foot touchdown point (1000 foot of air distance)
• Automatic speed brake deployment
• Autobrake usage or prompt application of manual wheel braking (Maximum manual braking data is only valid for automatic speed brakes. Autobrake data is valid for both automatic and manual speed brakes)
• Prompt initiation of reverse thrust (within 2 seconds of touchdown).

The conditions/assumptions for other models are generally similar to the above, however some variations do exist and operators are encouraged to check the notes on the Normal Configuration Landing Distance charts.

**Flying the Airplane**

The Boeing FCTM and FCOM have complete sections discussing adverse runway condition operations and techniques. These recommendations and procedures are consistent with the Normal Configuration Landing Distance information found in the QRH. Flight crews are reminded that if they deviate from these recommendations and procedures, they may need to include an appropriate allowance in their landing distance calculations.

The following provide Boeing recommended procedures.

**Approach, Flare and Touchdown**

On final approach, maintain a stable speed, descent rate and vertical/lateral flight path in the landing configuration. This is commonly referred to as the stabilized approach concept. Use the maximum landing flap available to minimize landing speed and landing distance.

After the flare is initiated, smoothly retard the thrust levers to idle and make small pitch attitude adjustments to maintain the desired descent rate to the runway. Ideally, main gear touchdown should occur simultaneously with thrust levers reaching idle. A smooth power reduction to idle also assists in controlling the natural nose-down pitch change associated with thrust reduction.

After main gear touchdown, initiate the landing roll procedure. Any delay increases the stopping distance.

**Note:** Make a normal landing; do not strive for a “smooth” touchdown. Floating above the runway before touchdown must be avoided because it uses a large portion of the available runway. The airplane should be landed as near the normal touchdown point as possible. Deceleration rate on the runway is approximately three times greater than in the air. Do not attempt to hold the nose wheels off the runway.

Autoland may lead to longer touchdowns than that assumed in the Boeing QRH performance data. Boeing autoland testing has shown an average touchdown point of 1500 feet from the threshold, with the possibility of the touchdown occurring as much as
2100 to 2500 feet from the threshold depending on the model. High threshold height will likely result in longer touchdowns. Heads-Up-Display (HUD) landing flare guidance (AIII) may reduce the average touchdown distance and dispersion; however these types of landings may still result in a touchdown point longer than the 1,000 foot touchdown point assumed in the Boeing QRH performance data. As such, operators are encouraged to monitor their touchdown statistics to determine if any adjustments for their operations are appropriate.

**Speed Brake Operation**

It is important for flight crews to remember that prompt deployment of speed brakes is extremely important to the effectiveness of the wheel brakes. Normally, speed brakes are armed to extend automatically. Both pilots should monitor speed brake extension after touchdown. In the event automatic extension fails, the speed brakes should be manually extended immediately. Boeing QRH landing advisory data is based on the use of automatic speed brakes. If manual speed brakes are used they should be deployed within 2 seconds after touchdown and the additional distance required should be considered.

**Braking During Landing Roll**

Use an appropriate autobrake setting or manually apply wheel brakes smoothly with steadily increasing pedal pressure as required for runway condition and runway length available. Maintain brake pressure until stopped or until desired taxi speed is reached.

Boeing recommends the autobrake system be used whenever the runway distance is limited, and when landing on a slippery runway. Use of autobrake will ensure prompt application of the wheel brakes following touchdown.

**Autobrake**

For normal operation of the autobrake system, select a deceleration setting. Settings include:

- **MAX** - Used when minimum stopping distance is required. Deceleration rate is less than that produced by full manual braking on a dry runway
- **3 or 4** - Should be used for wet or slippery runways or when landing rollout distance is limited
- **1 or 2** - These settings provide a moderate deceleration effect suitable for all routine (i.e., not slippery or contaminated runway) operations

On a slippery runway the autobrake deceleration rate of 3, 4, or maximum (Max), although selectable, may not be achievable. The deceleration rate will be limited by the runway friction available

**Note:** Available autobrake settings are airplane dependant. The FCTM for the specific airplane should be consulted.

After touchdown, crewmembers should be alert for autobrake disengagement annunciations. The pilot monitoring (PM) should notify the pilot flying (PF) anytime the autobrakes disengage.
If stopping distance is not assured with autobrakes engaged, the PF should immediately apply manual braking sufficient to ensure the maximum deceleration available within the remaining runway.

**Manual Braking**
Immediately after main gear touchdown, smoothly apply a constant brake pedal pressure for the desired braking. For short or slippery runways, use full brake pedal pressure.
- Do not attempt to modulate, pump or improve the braking by any other special techniques.
- Do not release the brake pedal pressure until the airplane speed has been reduced to a safe taxi speed.
- The antiskid system stops the airplane for all runway conditions in a shorter distance than is possible with either antiskid off or brake pedal modulation.

The antiskid system adapts pilot applied brake pressure to runway conditions by sensing an impending skid condition and adjusting the brake pressure to each individual wheel for maximum braking effort. When brakes are applied on a slippery runway, several skid cycles occur before the antiskid system establishes the right amount of brake pressure for the most effective braking.

If the pilot modulates the brake pedals, the antiskid system is forced to readjust the brake pressure to establish optimum braking. During this readjustment time, braking efficiency is lost.

Pilots may misinterpret the low available friction on extremely slippery runways at high speeds as an antiskid system failure. Pumping the brakes or turning off the antiskid system degrades braking effectiveness. Maintain steadily increasing brake pressure, allowing the antiskid system to function at its optimum.

**Note:** Although immediate braking is demonstrated in flight test and is the basis for the performance data, experience has shown manual braking techniques commonly seen in line operations involve a four to five second delay between main gear touchdown and brake pedal application. This delay may result in the addition of 800 to 1,000 feet of stopping distance. For this reason, autobrakes are highly recommended.

To achieve the QRH landing distances, the wheel brakes must be applied within 1 second after touchdown.

**Reverse Thrust Operation**
Awareness of the position of the forward and reverse thrust levers must be maintained during the landing phase. Improper seat position as well as the wearing of long jacket or shirt sleeves may cause inadvertent advancement of the forward thrust levers, preventing movement of the reverse thrust levers.

The position of the hand should be comfortable, permit easy access to the autothrottle disconnect switch, and allow control of all thrust levers, forward and reverse, through full range of motion.
Note: On a slippery runway, reverse thrust always reduces the “brake only” stopping distance. Reverse thrust is most effective at high speeds.

After touchdown, with the thrust levers at idle, raise the reverse thrust levers up and aft to the interlock position. As the thrust reversers reach the deployed position, apply reverse thrust as required. It is important to promptly apply reverse thrust. This reduces stopping distance on slippery runways.

Maintain reverse thrust as required, up to maximum, until the airspeed approaches 60 knots. At this point start reducing the reverse thrust so that the reverse thrust levers are moving down at a rate commensurate with the deceleration rate of the airplane. The thrust levers should be positioned to reverse idle by taxi speed, then to full down after the engines have decelerated to idle.

Note: If the stop is in question, maximum reverse thrust should be used until the stop is ensured.

The following should be noted:
- Boeing QRH landing advisory data is based on selection of reverse thrust within 2 seconds after touchdown.
- Waiting to apply reverse thrust until nose gear touchdown will increase the distance required to stop.
- The flight crew should always verify deployment of thrust reversers.
- Boeing advisory QRH “Normal” Configuration Landing Distance is based on all engine reverse thrust with corrections for reverser inoperative and no reverse thrust configurations:
  - 727, 757, 767, and 777 – all engine maximum reverse thrust as baseline
  - 737 – two engine No. 2 detent reverse thrust position as baseline
  - 707 and 747 – four engine maximum reverse thrust is baseline with corrections for two engine symmetrical reverse configuration and no reverse thrust.
- Boeing advisory QRH “Non-Normal” Configuration Landing Distance is based on maximum reverse thrust when available on operating engines.
- Reverse thrust will always reduce the distance required to stop the airplane on a slippery runway.
- Reverse thrust is required to achieve the Boeing QRH reference landing distance on a slippery runway.
Conclusion

Safe and successful landings, particularly on slippery runways, are the result of proper planning and flight crew adherence to proper procedures and techniques. The flight crew familiarity with the performance effect of runway conditions, the possibility of conflicting runway condition reports, the assumptions in the performance data, and the recommended pilot techniques required to achieve the best airplane stopping performance are important in ensuring safe and successful landings on slippery runways.

Boeing recommends operators have procedures to ensure that a full stop landing can be made on the runway to be used, in the conditions existing at the time of arrival and with the deceleration means and airplane configuration that will be used. This procedure needs to include a determination of whether conditions exist that may affect the safety of the flight and whether operations should be restricted or suspended. Pilots should stay informed, as applicable, of conditions such as airport and meteorological conditions that may affect the safety of the flight.

The Boeing QRH advisory data provided to FAA operators is unfactored (no additional distance margin). The Boeing QRH advisory data provided to operators who use JAA requirements includes an additional 15% distance margin. Operators are encouraged to add additional margin appropriate to their operations to ensure an acceptable landing distance is available. The FAA has released SAFO 06012 which requests US operators voluntarily add at least a 15% margin as an interim measure until their final rulemaking is completed.

Finally, Boeing encourages additional and more comprehensive dissemination of information to flight crews about aircraft characteristics and capabilities. Boeing supports industry efforts to improve training of airline flight crew involving performance limited landings.